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## Ratings Of Perceived Exertion Throughout An Ultramarathon During Carbohydrate Ingestion

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### Abstract

Ratings of perceived exertion (RPE) and their relation to selected physiological mediators during endurance exercise have been limited to laboratory settings. The present study characterized the pattern of change in perceptual responses and examined the relation between RPE and selected physiological variables during a long competitive sporting event, i.e., an ultramarathon race (68 km). A single-group design was employed in which all of the 28 subjects provided their perceptual ratings ( $11.9 \pm 0.2$ ) and heart rate (HR) ( $138 \pm 3$ ) periodically (every 5 km) throughout the ultramarathon, and selected physiological responses were measured before, once during (32 km), and immediately after the race. Runners drank approximately 1,000 ml of carbohydrate beverage each hour (60 gm carbohydrate hr.<sup>-1</sup>) and ate 2 or 3 carbohydrate gel packs per hour (25 gm each <sup>-1</sup>). RPE increased significantly throughout the course of the ultramarathon. No significant correlations were found between RPE and HR at any time throughout the ultramarathon. RPE averaged  $10.4 \pm 0.4$  at the beginning of the race (6.4 km) and  $15.4 \pm 0.4$  at the conclusion of the race. Subjects maintained  $76.9 \pm 1.1\%$  of maximal heart rate; however, there was a tendency for heart rate to drop significantly after 32 km. Significant time main effects were found for serum glucose, insulin, and cortisol throughout the race. However, no significant correlations were found between RPE and any of these physiological mediators. These data indicate that during an ultramarathon race there is a progressive increase in RPE without an accompanying increase in HR or decrease in blood glucose. Therefore, during competitive self-paced exercise the perceptual responses may be mediated through other neurological and physiological mechanisms.

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# RATINGS OF PERCEIVED EXERTION THROUGHOUT AN ULTRAMARATHON DURING CARBOHYDRATE INGESTION

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**Summary.**—Ratings of perceived exertion (RPE) and their relation to selected physiological mediators during endurance exercise have been limited to laboratory settings. The present study characterized the pattern of change in perceptual responses and examined the relation between RPE and selected physiological variables during a long competitive sporting event, i.e., an ultramarathon race (68 km). A single-group design was employed in which all of the 28 subjects provided their perceptual ratings ( $11.9 \pm 0.2$ ) and heart rate (HR) ( $138 \pm 3$ ) periodically (every 5 km) throughout the ultramarathon, and selected physiological responses were measured before, once during (32 km), and immediately after the race. Runners drank approximately 1,000 ml of carbohydrate beverage each hour ( $60 \text{ gm carbohydrate hr}^{-1}$ ) and ate 2 or 3 carbohydrate gel packs per hour ( $25 \text{ gm each}^{-1}$ ). RPE increased significantly throughout the course of the ultramarathon. No significant correlations were found between RPE and HR at any time throughout the ultramarathon. RPE averaged  $10.4 \pm 0.4$  at the beginning of the race (6.4 km) and  $15.4 \pm 0.4$  at the conclusion of the race. Subjects maintained  $76.9 \pm 1.1\%$  of maximal heart rate; however, there was a tendency for heart rate to drop significantly after 32 km. Significant time main effects were found for serum glucose, insulin, and cortisol throughout the race. However, no significant correlations were found between RPE and any of these physiological mediators. These data indicate that during an ultramarathon race there is a progressive increase in RPE without an accompanying increase in HR or decrease in blood glucose. Therefore, during competitive self-paced exercise the perceptual responses may be mediated through other neurological and physiological mechanisms.

A majority of studies examining the perceptual responses and their relation to physiological changes during endurance exercise have been limited to

laboratory settings in which subjects performed a constant-load exercise for a prolonged period or until they could no longer maintain the target work rate (Robertson, Stanko, Goss, Spina, Reilly, & Greenawalt, 1990; Burgess, Robertson, Davis, & Norris, 1991; Kang, Robertson, Goss, DaSilva, Visich, Suminski, Utter, & Denys, 1996; Utter, Kang, Nieman, & Warren, 1997; Utter, Kang, Nieman, Williams, Robertson, Henson, Davis, & Butterworth, 1999). Designs that employ an exercise of constant intensity have advantages in controlling for factors associated with the variability of intensity. However, the external validity of the research using such exercise protocols may be limited. This is because during a sport competition, particularly an extended endurance race such as a marathon or ultramarathon, the intensity at which exercise is performed is typically self-chosen, and athletes pace their effort in an attempt to maximize performance.

Physiological factors mediating the perceptual responses during dynamic exercise are both central and peripheral in origin. For example, previous studies have reported a linear relationship between ratings of perceived exertion (RPE) and heart rate (HR) (Borg, 1972; Stamford & Noble, 1976; Hampson, Gibson, Lambert, & Noakes, 2001), although this relation can be altered by environmental conditions (Pandolf, Cafarelli, Noble, & Metz, 1972; Kamon, Pandolf, & Cafarelli, 1974) and pedal frequency (Pandolf & Noble, 1973). In addition, our recent double-blind laboratory based studies with carbohydrate feeding demonstrated a progressive increase in RPE as a result of a continuing reduction in blood glucose and carbohydrate energy substrates during prolonged strenuous exercise (Kang, *et al.*, 1996; Utter, *et al.*, 1997, 1999). To date, it remains unclear as to how RPE responds to self-paced exercise and whether physiological and perceptual links exist during an actual sporting competition. Under such natural circumstances where intensity of exercise is self-chosen, it is likely that the perceptual responses may not be proportional to the magnitude of the physiological alterations induced by exercise because subjects will attempt to maintain their reserve capacity to complete the race. This point is reinforced in a recent review by Hampson, *et al.* (2001) who stated that the precise relationship between the regulation of exercise intensity and perceived exertion can not be determined at present since most research on perceived exertion has utilized prescribed exercise intensities, which may invoke a different exertion response than when the intensities are chosen by the individual undertaking the exercise (p. 949).

Given the scarcity of literature pertaining to perceived exertion and sports competition, the present study was undertaken to characterize the pattern of change in perceptual responses and to examine the relation between RPE and selected physiological variables during an ultramarathon race. This research objective was achieved by using a single-group design in which

all subjects provided their perceptual ratings periodically throughout the ultramarathon and their physiological responses were measured before, once during, and immediately after the race. We hypothesized that there would be a progressive increase in RPE, along with significant correlations to selected physiological variables throughout the ultramarathon race.

## METHOD

### *Subjects*

Ultramarathon runners were recruited through a letter of invitation prior to the April 7, 2001, Umstead Ultramarathon, in Raleigh, North Carolina. The Umstead Ultramarathon is a 16-km closed loop which is run five times for a total of 80 km. Male and female runners ranging in age from 20 to 70 years were accepted into the study if they had run at least one competitive ultramarathon and were willing to adhere to all aspects of the research design. Informed written consent was obtained from each subject, and the experimental procedures were in accord with the policy statements of the institutional review board of Appalachian State University.

### *Research Design*

Four to six weeks prior to the ultramarathon race event, subjects reported to the ASU Human Performance Lab for orientation and measurement of body composition and cardiorespiratory fitness. Basic demographic and training data were obtained through a questionnaire. To control for diet, during orientation a dietitian instructed the runners to follow a diet high in carbohydrate during the seven days prior to the race event (through use of a food list) and record intake in a food record. Nutrient intake was assessed using the computerized dietary analysis system, Food Processor Plus, Version 6.0 (ESHA Research, Salem, Oregon). Body composition was assessed from hydrostatic weighing and measured residual lung volume, and  $\text{VO}_2$  max assessed using a graded maximal protocol adapted for runners as described in earlier studies from our group (Utter, *et al.*, 1997, 1999). Oxygen uptake and ventilation were measured using the MedGraphics CPX metabolic system (MedGraphics Corporation., St. Paul, Minnesota). Maximal heart rate was measured using a chest heart-rate monitor (Polar Electro Inc., Woodbury, New York).

During maximal testing ratings of perceived exertion (RPE) were obtained using the Borg 15-point rating of perceived exertion scale to establish the low and high rating anchors (Borg, 1982). The definition of RPE and instructions for the use of the rating scale were read by the subject prior to the exercise test. The instructions emphasized that the perceptual ratings should reflect sensations of exertion, strain, discomfort, or fatigue in the limbs and respiratory system. Each rating was limited to a single numbered response and corresponded to the overall body. Each subject also received a

pocket-sized RPE scale to be used during training in the 2–4 weeks prior the race. The distribution of the pocket-sized RPE scale was done to promote familiarization with the rating procedure during training and to enhance recall capabilities of the perceptual responses when assessed during the actual ultramarathon.

On the day of the race, the 29 runners reported to the start area at 4:30–5:00 am. After sitting for 10–15 min., blood samples were collected, i.e., for plasma volume, glucose, insulin, and cortisol. Body mass was measured, and a chest heart-rate monitor was attached to each runner. Subjects avoided food or beverages containing calories or caffeine for six hours prior to the race start other than a carbohydrate beverage supplied by the research team. Carbohydrate beverages were supplied by the Gatorade Sports Science Institute (Barrington, Illinois). Each runner ingested 750 ml of beverage approximately 30 min. prior to the start of the race (5:30 am). During the race, runners drank approximately 1,000 ml of beverage each hour (60 gm carbohydrate/hr.). Research assistants were positioned every 5 km (three aid stations on the 16-km loop) to deliver carbohydrate beverage bottles which contained 500 ml fluid. Runners ingested the fluid from two bottles per hour and also ate 2 or 3 carbohydrate gel packs per hour (each containing 25 gm). Runners agreed to avoid all other beverages and food before and during the race. The research assistants recorded heart rates and ratings of perceived exertion (RPE 6–20) from each runner approximately every 5 km.

After running 32 km, and then again after crossing the 80-km race finish line, blood samples were collected from subjects in the seated position within 5 min. (about one minute to walk the subject to the collection area and get them seated). Due to extreme environmental conditions (see Results section), some runners were unable to complete the race due to fatigue or the 12-hr. limit (imposed by the research team), and blood samples were collected from these runners as long as they had run 50 km or more (13 runners completed all 80 km). Body mass was also measured at 32 km and postrace. A postrace questionnaire verified compliance to all aspects of the research design by each runner.

#### *Hormones and Plasma Volume*

Blood samples were drawn from an antecubital vein with subjects in the seated position at the location of the race site. Plasma cortisol was assayed using the competitive solid-phase  $^{125}\text{I}$  radioimmunoassay (RIA) technique (Diagnostic Products Corporation, Los Angeles, California). RIA kits were also used to measure plasma concentrations of insulin according to manufacturers' instructions (Diagnostic Products Corporation, Los Angeles, California). Plasma was analyzed spectrophotometrically for glucose. Plasma volume changes were estimated using the method of Dill and Costill (1974).

### Statistical Analysis

Statistical significance was set at  $p < .05$ , and values expressed as  $M \pm SE$ . RPE, heart-rate, and blood parameters measured during the marathon were analyzed using a one-way repeated-measures analysis of variance. If the time main effect was significant for RPE or heart rate ( $p \leq .05$ ), the changes from km 6.4 were compared using Student  $t$  tests. For these multiple comparisons across time points, a Bonferroni adjustment was made, with statistical significance set at  $p < .001$ . If the time main effect was significant for any of the blood parameters at  $p \leq .05$ , the change from baseline for the 32-km and postrace values were compared using Student  $t$  tests. For these two multiple comparisons, a Bonferroni adjustment was made, with statistical significance set at  $p < .025$ . Pearson product-moment correlations were used to test the associations among RPE, heart rate, and glucose, insulin, cortisol at the 32-km and postrace measures.

### RESULTS

Twenty-eight ultramarathoners (25 men and 3 women) fully complied with all protocol requirements. Age, height, body mass, training history, racing experience, and cardiorespiratory fitness data are presented in Table 1. Overall, the subjects were experienced and committed to regular training, but the subjects were well below elite status. The prerace diet measured from 7-day food records indicated a mean energy intake of  $11.2 \pm 0.2$  MJ day<sup>-1</sup>, carbohydrate  $55.3 \pm 2.8\%$  total energy, and fat  $29.0 \pm 1.8\%$  total energy.

TABLE 1  
SUBJECTS' CHARACTERISTICS (N = 28)

Characteristic	M	SE
Age, yr.	47.8	2.3
Height, m	1.7	0.01
Body mass, kg	76.5	3.9
Running experience, yr.	14.0	1.7
Training distance, km · wk. <sup>-1</sup>	64.1	5.8
Ultramarathons raced	20.8	5.2
VO <sub>2</sub> max, ml · kg <sup>-1</sup> · min. <sup>-1</sup>	47.9	1.4
VE <sub>max</sub> , l min. <sup>-1</sup>	136	4
HR <sub>max</sub> , beats · min. <sup>-1</sup>	180	7
RER <sub>max</sub>	1.15	±0.01

Environmental conditions at the 6:00 A.M. race start were 18°C and 90% relative humidity, at 10:00 A.M. 24°C and 60% rh, at 2:00 P.M. 31°C and 40% rh, and at 6:00 P.M. 30°C and 40% rh. Ultramarathon race performance measures are summarized in Table 2. Fluid intake was close to the 1 l/hr. goal throughout the race (mean intake of 57 gm carbohydrate per

hour), resulting in modest but nonsignificant changes in body mass and plasma volume. Runners also averaged  $2.3 \pm 0.2$  gel packs or 58 gm of carbohydrate per hour. Subjects ran a mean of 68 km (range 48 to 80 km) in 9.8 hr. (range 5 to 12 hr.).

TABLE 2  
RACE PERFORMANCE MEASURES ( $N=28$ )

Characteristic	<i>M</i>	<i>SE</i>
Average RPE	11.9	0.2
End RPE	15.4	0.4
Average HR, beats $\cdot$ min. <sup>-1</sup>	138	3
Average %HR <sub>max</sub>	76.9	1.1
Race distance, km	67.6	1.5
Race time, hr.	9.77	0.35
Fluid intake, l $\cdot$ hr. <sup>-1</sup>	0.95	0.05
Body mass loss, kg	-1.83	0.49
Plasma volume change, %	-4.43	0.38

Subjects maintained an intensity of approximately 75% of maximum heart rate throughout the ultramarathon race (Table 2 and Fig. 1). However, there was a tendency for heart rate to drop significantly after 32 km of the race. RPE increased significantly throughout the course of the ultramarathon (Table 2 and Fig. 2), averaging  $10.4 \pm 0.4$  at the beginning of the race (at 6.4 km) and  $15.4 \pm 0.4$  at the conclusion of the race. A significant increase in RPE was found at 22.5 km and at every subsequent 5 km throughout the

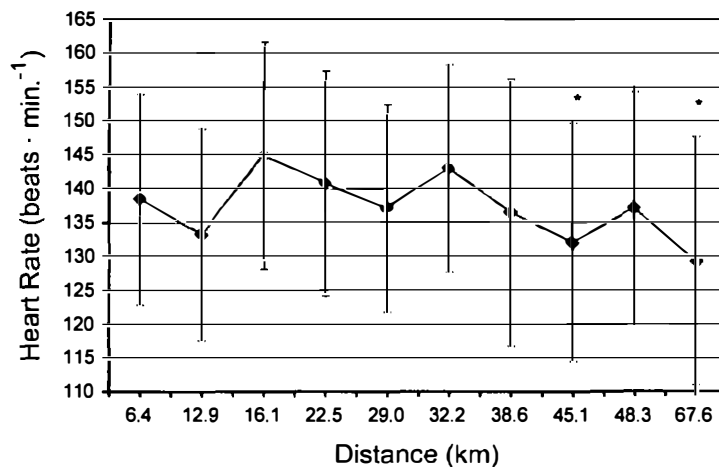


FIG. 1. Heart-rate response ( $M \pm SE$ ) over the course of a competitive ultramarathon. Time main effect:  $F_{9,234} = 7.75$ ,  $p < .001$ . \* $p < .001$  change from km 6.4.

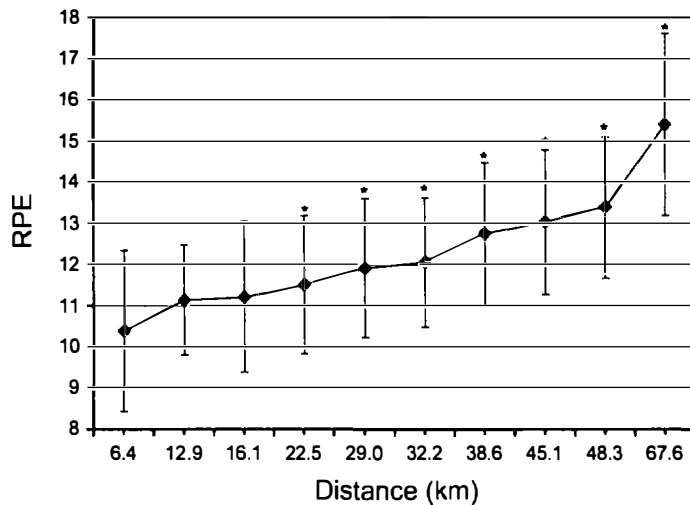


FIG. 2. Ratings of perceived exertion ( $M \pm SE$ ) over the course of a competitive ultramarathon. Time main effect:  $F_{9,234} = 35.88$ ,  $p < .001$ . \* $p < .001$  change from km 6.4.

race. Heart rate (range: 114–157) did not significantly correlate with RPE (range: 8.6–15.4) at any time throughout the ultramarathon.

Significant time main effects were found for serum glucose, insulin, and cortisol throughout the race (Table 3). Glucose and insulin rose significantly at 32 km and then fell closer to prerace levels by race end. Serum cortisol tended to rise throughout the race with significant increases found at post-race. A modest but nonsignificant correlation was found for ending RPE with post-race cortisol ( $r = .35$ ,  $p = .07$ ), but no significant correlations were found between RPE and glucose, insulin, and cortisol.

TABLE 3  
GLUCOSE AND HORMONE VALUES THROUGHOUT AN ULTRAMARATHON: MEANS AND STANDARD ERRORS

Parameter	Prerace		32 km		Postrace		<i>p</i> Time
	<i>M</i>	<i>SE</i>	<i>M</i>	<i>SE</i>	<i>M</i>	<i>SE</i>	
Serum glucose, mmol/l	7.4	0.40	8.4	0.29*	7.4	0.35†	<.001
Serum insulin, pmol/l	46.7	5.6	85.0	10.6*	45.8	4.4†	.002
Serum cortisol, nmol/l	627	25	703	45	1164	92†	<.001

\*Significantly different from Prerace at  $p < .001$ . †Significantly different from 32-km at  $p < .001$ .

### DISCUSSION

In the present study, we found a progressive increase in RPE throughout the ultramarathon race. Such an increase in RPE is similar to what was observed during prolonged exercise of constant load in a laboratory-based



setting. Among many mediators that can affect the perception of exertion during exercise of prolonged duration, carbohydrate availability has been one of the most compelling (Burgess, *et al.*, 1991; Kang, *et al.*, 1996; Utter, *et al.*, 1997, 1999). Previous studies have indicated a reduction in muscle glycogen of more than 90% during ultramarathons (Noakes, Lambert, Lambert, McArthur, Myburgh, & Spinndler-Benade, 1988). Carbohydrate utilization or muscle glycogen was not assessed in the present study. However, the reduction in muscle glycogen with this volume of exercise may have also occurred as serum level of cortisol immediately postrace increased significantly and became almost twice as much as the prerace value (Table 3). In addition, a modest but nonsignificant correlation was found for ending RPE with postrace cortisol ( $r = .35$ ,  $p = .07$ ). Cortisol is a glucoregulatory hormone and normally increases in response to a decrease in endogenous carbohydrate substrate. Its secretion functions to ensure a continuous supply to energy to meet the metabolic demand imposed by the activity. In the present study, it is possible that depletion of muscle glycogen and its related metabolic disturbance may have served as sensory cues necessary to affect the perception of exertion. It is believed that muscle possesses sensory nerves capable of sensing ATP flux and metabolic changes (Hampson, *et al.*, 2001). The mechanism underlying how the reduction in energy substrate potentiates the perception of exertion has been ascribed to the increase in feedforward commands from the motor cortex as a result of increased motor-unit recruitment (Robertson, *et al.*, 1990). Thus increased motor commands, thought to compensate for the fatigue of muscle fibers, will then increase the magnitude of corollary signals, thereby intensifying the perception of exertion.

Given the extraordinary nature of an ultramarathon, it is conceivable that many other physiological changes can also be effective in intensifying the perception of exertion. Among the possibilities, muscular strain and body temperature appear to be the most plausible candidates serving to augment perceived exertion. Although not measured, it is highly possible that tissue damage of various extents within the exercising muscle may have occurred in our subjects. If so, this can produce a strong afferent stimulus to the central nervous system (Hampson, *et al.*, 2001). In addition, the magnitude of decrease in body mass as well as plasma volume following the race as shown in Table 2 suggests that our subjects were dehydrated after the competition. The loss of body fluid may have also resulted in a rise in body temperature secondary to the exercise and environmental stressors, which has been linked to an increase in perceived exertion (Farrell, Gates, & Maksud, 1982; Pivarnik & Senay, 1986).

The increase in RPE, however, cannot be attributable to changes in heart rate and blood glucose that have been considered to be central and

peripheral mediators, respectively (Noble & Robertson, 1996). RPE systematically increased as the race progressed; however, this was not accompanied by a corresponding change in these physiological parameters. The dissociation between RPE and heart rate was also reported in previous studies in which subjects exercised under hyperthermic environmental conditions (Pandolf, *et al.*, 1972; Kamon, *et al.*, 1974) and at different pedaling frequencies (Pandolf & Noble, 1973). The lack of serial measurements of heart rate in the present study should also be viewed as a limitation. It is possible that the single heart-rate values obtained may not have reflected steady state. The fact that the level of blood glucose following exercise remained unchanged from the pretest values (Table 3) was mainly because our subjects were instructed to follow a high carbohydrate diet during seven days prior to the race and were given carbohydrate beverages at a rate of  $60 \text{ gm} \cdot \text{hr}^{-1}$  during the race.

Despite the fact that the RPE responses observed in the present investigation were similar to those of previous laboratory studies in which exercise intensity was held constant, the underlying mechanisms mediating the perceptual responses in this free-living athletic competition were different. Researchers should evaluate whether the level of motor outflow set initially during self-paced exercise is altered by afferent feedback such as metabolic disturbance, hormonal alterations, or muscular strain, once performance is underway. This research will assist in establishing whether the perception of exertion reported during a self-paced endurance event is dependent upon the integration of both the feedforward and feedback processes. In contrast, during exercise of a constant load such active communication between the feedforward and feedback processes may not exist as subjects are required just to maintain a given power output for as long as possible. Perceived exertion under these circumstances is mainly modulated by sensory inputs, whereas motor commands are relatively constant until energy substrates are reduced significantly. It should be mentioned that at present this proposal remains hypothetical but can be tested by using an experimental protocol which allows discrimination between feedforward and feedback regulatory processes.

In conclusion, the present investigation showed a progressive increase in RPE during an ultramarathon race despite undergoing carbohydrate ingestion. This increased perception of effort, however, was not associated with either an increase in heart rate or a decrease in blood borne glucose. Researchers should examine whether these findings are a result of a reduction in energy substrates in conjunction with increases in muscular strain and body temperature.

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